Automating pressure ulcer risk assessment using documented patient data

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\section*{Abstract}

Objective: A rule-based prototype decision support tool; Braden-scale based Automated Risk-assessment Tool (BART) was developed to test whether pressure ulcer risk scores can be determined automatically based on the documented patient data.

Methods: The data items required for assessing pressure ulcer risk were identified by analyzing the parameter definitions of the Braden scale and by consulting the nurses specialized in pressure ulcer prevention and care. Documentation coverage and formats of the required data was evaluated. The decision rules were developed based on the inputs from the expert nurses, and were implemented as a web-based prototype tool, BART. The agreement rates between nurses and BART on assigning scores to the six Braden-scale parameters were calculated with 39 convenience samples of patient data.

Results: Although several items required for the automated decision were not found from the documentation, the majority of the required data items were documented with feasible formats (i.e., coded lists or free text with nominal or numeric values) for algorithmic processing. When evaluated with 39 test cases, BART and the nurses showed varying levels of agreement (from “slight” to “substantial”) on assigning scores for the six parameters of the Braden scale. They showed “fair” level of agreement with an “at risk” decision.

Conclusion: BART has limitations that need to be addressed through future enhancements. However, it demonstrates potential for reuse of documented patient data to automatically populate pressure ulcer risk using the Braden scale.

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\section*{1. Introduction}

Ideally, detailed patient data, once collected and recorded in a documentation system, should be reused to serve multiple purposes such as decision making for patient care and outcome evaluation [1]. Such data reusability may increase workflow efficiency by eliminating redundant data collection and documentation, and may promote quality of care by providing a data for evidence-based practice. Availability

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of data is one of the key requirements for successful implementation of Clinical Decision Support Systems (CDSS) [2,3]. Studies have shown that nurses spend up to 25% of their time on documentation of care activities [4,5]. However, the extent to which nursing documentation provides the data necessary for the decisions related to patient care has been questioned [6,7].

A pressure ulcer is a serious concern in terms of healthcare quality and fiscal implications, as it causes significant discomfort to patients and results in high treatment cost to payers [8–10]. Consistently and accurately assessing and documenting risk is a critical first step to pressure ulcer prevention. A few studies reported automating pressure ulcer risk assessment based on expert rules or clinical guidelines to improve the quality of risk assessment [11,12]. However, details on the design of these risk assessment tools, including sources of input data for algorithmic processing have not been described.

The purpose of this study was to explore whether pressure ulcer risk can be determined based on patient data routinely documented in the patient record. Three key aspects of model building were addressed: (1) data requirements, (2) degree of data completion in current documentation system, and (3) accuracy of a risk score model for pressure. We developed BART (Braden-scale based Automated Risk-assessment Tool), a prototype rule-based CDSS that automatically calculates risk for developing a pressure ulcer based on the Braden scale using the documented patient data. The goal is to use this tool in a new electronic bedside nursing documentation system that is being developed at Partners Healthcare System (PHS). Our study was conducted at one of the academic medical centers affiliated with PHS and Harvard Medical School in Boston.

2. Background

2.1. Pressure ulcer as an indicator for quality of care

A pressure ulcer is one of the most serious safety concerns related to hospitalizations. According to Center for Medicare and Medicaid (CMS)’s research, about 257,412 cases were reported as having a pressure ulcer as a secondary diagnosis in fiscal year of 2007, and the average treatment cost per hospital stay was estimated to be $43,180 [8]. In addition, the 10th Annual International Pressure Ulcer Prevalence Survey (IPUPS) revealed that about 50% of all adult patients in acute care facilities were at high risk for developing pressure ulcers [13]. Considering skin integrity as a reflection of quality of nursing care, Medicare no longer reimburses hospital-acquired pressure ulcers as of October 2008 [8–10].

Assessing pressure ulcer risk is a complicated decision process that requires incorporating various aspects of patient status [14,15]. In general, nurses regularly assess the risk of developing pressure ulcer over the course of hospitalization and update nursing care plans as necessary when the risk level changes. Accurately assessing the risk is the first step of providing preventive measures that effectively mitigate the identified risk factors.

2.2. The Braden scale

Braden scale is one of the most widely adopted standardized assessment scales for pressure ulcer risk assessment [16–18]. It consists of 6 parameters that reflect patient conditions regarding nutrition, sensory perception, activity, mobility, moisture exposure, and the susceptibility to friction and skin shearing. These parameters are assessed using ordinal scores of 1–4, except the Friction & Shear parameter, which is scored from 1 to 3 [19]. Each score of each parameter has a narrative definition, which provides guidance on determining pressure ulcer risks with the Braden scale [19].

2.3. The current workflow of assessing and documenting pressure ulcer risk using the Braden scale at the study hospital

At the study site, pressure ulcer risk assessment with the Braden scale is included as an initial nursing assessment item and it is used to develop the initial nursing plan of care. After the initial assessment, nurses regularly assess (i.e., at least once every shift) the pressure ulcer risk over the course of hospitalization, and the nursing plan of care is updated as the Braden risk score changes. This continuous assessment of pressure ulcer risk is documented on flow sheets with only the risk score, which is the sum of the six parameter scores. The inpatient documentation at this hospital is currently being done with paper forms. Therefore nurses first assign 6 parameter scores in a separate sheet, which is not a part of the formal documentation, by pulling and aggregating various patient data manually before documenting the risk score on flow sheets. The full parameter definitions are available as a reference: a page of the complete Braden scale form that includes detailed definitions of each parameter and the associated scores is filed in the back of the patient chart so that nurses can refer to it as necessary.

Due to the limited capability of paper-based patient records in supporting data retrieval and aggregation, nurses often reassess patients or browse patient charts to seek relevant information to score the 6 parameters of the Braden scale which is time-consuming and disruptive to their workflow [20]. However, a more serious concern with such use of the Braden scale is the lack of a link between the care decisions and outcomes. This lack of connection will make it challenging to accumulate evidence that can be used to improve nursing practice [21–23]. Computerizing the documentation system will not solve this problem unless the evidence linkage is carefully incorporated into the system.

3. Methods

3.1. Prototype tool development

3.1.1. Expert nursing panel

An expert nursing panel was formed with three experienced nurses who also serve the pressure ulcer prevention task force at the study hospital. The expert nursing panel participated in identifying required data items, developing decision rules,
were then classified into: using them for algorithmic processing. These descriptions to determine the documentation format, and feasibility of the team collaboratively reviewed the identified data items. Once the accuracy of the extracted descriptions was verified, relatively straightforward and little correction was required.

expert nurses. opinions and the final decisions were approved by all three each expert nurse had the equal opportunities to present her

Although no formal consensus building process was adopted discussed any questions or concerns in face to face meetings.

The reviewers individually reviewed the provided tables and

Fig. 1 – Extracting patient status descriptions from the score definitions of the Sensory Perception parameter.

and evaluating the prototype tool through the course of this study.

3.1.2. Data item identification

Each parameter score of the Braden scale has a detailed description of the patient conditions that meet the score definition. Therefore, we first manually extracted patient status descriptions from the score definitions. Fig. 1 shows extracting patient status descriptions from the definitions provided for the scores of the Sensory Perception parameter. Here, we extracted 3 discrete patient status descriptions such as “response level,” “ability to feel pain or discomfort” and “ability to communicate pain or discomfort.”

A table with the descriptions extracted from the parameter definitions was presented to the expert nursing panel to determine (1) whether descriptions were accurately extracted from the definitions (i.e., whether the definitions were correctly interpreted by the investigator who conducted the extraction) and (2) whether extracted descriptions were documented in the paper charts. The expert reviewers were provided with a table where the parameter definitions and the patient descriptions extracted from the definitions are aligned side by side. The reviewers individually reviewed the provided tables and discussed any questions or concerns in face to face meetings. Although no formal consensus building process was adopted the investigator who facilitated the discussions ensured that each expert nurse had the equal opportunities to present her opinions and the final decisions were approved by all three expert nurses.

The review of extracted patient status descriptions was relatively straightforward and little correction was required. Once the accuracy of the extracted descriptions was verified, the team collaboratively reviewed the identified data items to determine the documentation format, and feasibility of using them for algorithmic processing. These descriptions were then classified into:

Group 1: routinely documented using coded lists, nominal free texts, or numeric free texts (e.g., Glasgow coma scale, body weight, diet type)

Group 2: routinely documented but in a free-text format requiring minimal to moderate manipulation (i.e., encoding) before use (e.g., relevant medical diagnosis, oral intake amount)

Group 3: routinely documented as text narratives requiring extensive manipulation before use (e.g., ability to change body position, ability to communicate pain)

Group 4: data not routinely documented (e.g., frequency and amount of physical activities, frequency of bed linen change)

Not all status descriptions we extracted – especially those fell in the Group 3 or 4 – were, however, feasible as input data. These status descriptions have the level of abstraction that is not appropriate as a routine documentation item. Therefore, we analyzed such descriptions further to identify the better defined discrete descriptions which reflect the same patient status described in the original descriptions, but which are more consistently documented in patient charts (i.e., satisfies the characteristics of Group 1 or 2).

For example, “response level” from Fig. 1 is the description that can be readily used as an input data item, as it is obtained easily and fed directly to the decision rules. This “response level” is captured by the standardized assessment Glasgow Coma Scale item “best eye opening,” which is consistently documented in the patient charts [24]. On the other hand, “patient’s ability to feel pain or discomfort” is not feasible as an input data because it is assessed for specific patients with known sensory problems thus less consistently documented in the patient charts. Even if it is documented it is very likely to be hidden in narrative nursing progress notes. Therefore this item required further investigation to identify alternative data items that are more consistently documented in a structured way.

3.1.3. Decision rule development

The investigator produced a table where the parameters, the patient status descriptions extracted from the parameter definitions, and the data items identified as relevant to the patient status appeared in the descriptions are shown side by side. Based on this table, the expert nursing panel reconstructed each score definition of each parameter with the identified data items, by defining their values or value ranges and by identifying the order of association among relevant data items. This was done primarily using the data items from groups 1 and 2. When the data items from the two groups were not sufficient to lead to a score decision, the data items from groups 3 and 4 were also used. This was done through a series of open discussions by reaching consensus. The same efforts previously described were made to assure the quality of decisions derived in the meetings.

The If-Then rules were created by the investigator (HK) for each parameter based on the reconstructed parameter-score definitions. The score definitions of a parameter were combined to a series of rule conditionals of that parameter. The
rules were put into diagrams for easy review then presented to the expert nursing panel for verification (Fig. 2). The expert nursing panel reviewed the diagram and verified that they correctly represented the decision algorithms that they produced through the previous discussions.

The decision rules were then tested with patient scenarios. Each expert nurse prepared 4 test scenarios that reflected patients with different levels of acuity that they usually encounter in the practice. The scenarios were created by specifying the values for the data items identified in the previous steps. We did not intend to reflect the specific patient characteristics related to the data items included in the decision rules as there are too many variations to cover. In addition to correcting any errors in the logic, the rules were streamlined by eliminating any redundant conditions through a “dry run” with the 12 test scenarios. The data item lists were also revised accordingly by eliminating unused ones.

3.1.4. Constructing BART
Once the rules were considered to be robust after several iterations of review and revision, the prototype tool BART was implemented as a web-based tool with JavaScript. The algorithms were tested with the same 12 test scenarios used in the previous step to correct any encoding errors. We did not implement a backend database for this pilot. Therefore BART was designed to take the required data though the series of data entry screens then to generate the parameter scores “on the fly.” Fig. 3 shows the screen shots of a data entry screen and the result screen.

3.2. Prototype evaluation

3.2.1. Data collection
A paper-based data collection packet that consisted of a full Braden scale form and a series of patient data intake forms were created. In the data collection packet, the data items were presented in 9 sections where the data items were grouped based on their physical and functional domains (not by the related Braden parameters) to minimize the risk of introducing bias in data collection. Every data item was treated as mandatory.

The expert panel suggested looking into three data items that are not part of the Braden scale but strongly believed to have relations to pressure ulcer risk according to their experiences in pressure ulcer care. These items are: “homelessness,” “transferred from long term care facilities” and “has been immobile longer than 4 h due to surgeries or procedures.” These items were not incorporated into BART but included to the data collection packet to check their relationships with pressure ulcer risk.

Four nurses who had at least 1 year of clinical experience were recruited from the inpatient medical or surgical units at the study hospital. To minimize assessment bias, the data items were grouped by physiological and functional domain not by related Braden scale parameters in the data intake form. In addition to this, data collecting nurses were not involved in any of the experts’ discussion sessions and not aware of ongoing study. Each nurse collected the data for 10 convenience samples of patients that they take care of in her unit using the data collection packets. They first completed the Braden scale assessment form then filled in the data intake form to minimize introducing a bias to their usual practice of assigning Braden scores by assessing the patients to complete the data assessment forms first.

Data collection was done either by (1) copying the data from a patient’s chart if the patient was assessed and the data was documented less than 4 h prior to the data collection time, or (2) reassessing the patient. These assessment required generation of data not documented in the patient charts. To avoid interruptions to their patient care responsibilities, data collection was done during their off-duty time.

3.2.2. Score comparison
The data was transcribed from the data collection packet to BART. The scores generated by BART and assigned by the nurses were put into a data table to test the agreement. The analysis was done using Statistical Analysis System (SAS), version 9.2 (SAS Institute, Cary, North Carolina).

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3 Contact the corresponding author for the URL to the tool.
Fig. 3 – The BART graphical user interface. (©copyright Partners Healthcare System, Inc. with funding provided by Siemens Medical Solutions USA, Inc.).

<table>
<thead>
<tr>
<th>Documentation formats/availability</th>
<th>Total Data item counts ((a))</th>
<th>Used in the rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I: in a readily usable format, no manipulation required</td>
<td>12 (8)</td>
<td>12 (8)</td>
</tr>
<tr>
<td>Group II: minimal to moderate manipulation required</td>
<td>12 (11)</td>
<td>11 (10)</td>
</tr>
<tr>
<td>Group III: extensive manipulation required</td>
<td>2 (2)</td>
<td>0</td>
</tr>
<tr>
<td>Group IV: not documented</td>
<td>10 (10)</td>
<td>7 (7)</td>
</tr>
<tr>
<td>Column total</td>
<td>36 (31)</td>
<td>30 (25)</td>
</tr>
</tbody>
</table>

Several data items were used in scoring multiple parameters. For example, the sensory perception status can imply the activity and mobility status to some extent. Also, activity status and mobility status imply the possibility of having skin friction and shear. Therefore, there exist overlaps in the data items used to determine Sensory Perception, Activity, Mobility and Friction & Shear. The Friction & Shear parameter was associated with the most data items, requiring 11 data items in the rule. Activity and Moisture Exposure were the two parameters associated with the least data items, requiring 4 items each. Sensory Perception and Mobility required 5 data items each, and Nutritional Status required 9 data items for the scoring decision.

\(a\) Number of data items that came from the parameter definitions.

4. Results

4.1. Data requirements and completion in current documentation

Table 1 shows the frequency distributions of the required patient status descriptions by documentation formats and availability. Thirty six data items were identified as relevant to the pressure ulcer risk assessment with the Braden scale. About 86% of them came from the parameter definitions and the remaining 14% were those identified as necessary by the expert panel. Note that the additional three items (i.e., “homelessness,” “transfer history” and “immobility history”) that were added to the data collection packet were not included in this analysis. Six data items extracted from the definitions were not used in the rule because they were deemed less critical in determining the risk scores or redundant as the same information can be drawn using the other data items.

The examples of the items deemed redundant are “ability to bear body weight”, “skin shearing occurrence while moving” and “spasticity or contracture that causes friction.” The experts judged that the same information can be delivered with the other items that are more regularly assessed and documented in daily practice, such as “frequent sliding down,” “ability to walk or sit,” and “assisted bed mobility”. The items deemed having less practical significance in the study hospital are “fluid intake while oral intake is very poor”, “oral supplement intake” and “protein intake amount”. The experts agreed that the sufficiency of intake of the prescribed nutrition (oral or non-oral intake) determines the nutritional status and these specifics rarely affect the overall decision. For example, nurses consider the nutritional status is adequate if the patient eats over half of the meals regardless of having supplement or not.
4.2 Accuracy of BART

Thirty-nine cases were included in the analysis excluding one that did not have manually assigned Braden scale scores. The one case that did not have a mandatory data item required for scoring the Friction & Shear parameter was excluded from only the analyses requiring that parameter score. The mean age of the 39 patients was 58.7 (s.d. = 19.4). About 54% of the cases were male and 51% were surgical patients. Ten patients had immobility history of longer than 4 h before admission, 3 patients had been transferred from long term care facilities, and only one patient was homeless. The sample included in the analysis is described in Table 2.

Agreements between the prototype tool and the nurses are presented in Table 3. The agreement rates varied by the parameters: Activity was the parameter with most agreement and Nutrition was the one with the least. When the chance agreement was corrected, the Activity parameter was still most agreed (“substantial” agreement) while the Moisture Exposure parameter was the least agreed (“slight” agreement). The remaining 4 parameters showed “moderate” agreement. The Sensory Perception parameter showed maximum 2 points difference in the assigned scores but the remaining parameters differed by 1 point between the two methods.

The maximum difference in the risk scores assigned by the two methods was 3 points. The mean difference of the risk scores assigned by the two methods was 0.5, which was statistically significant at the 95% significance level. At the study site, preventive measures are required when the risk score is less than 19. The chance corrected agreement of this “at risk” decisions made by the two methods was 0.38, indicating a “fair” level of agreement.

The immobility group showed lower mean risk scores and higher mean “at risk” decision rates, both in manual assessment and the BART assessment. The differences were statistically significant when tested with the Wilcoxon two-sample test and the Chi-square with Fisher’s exact test (Table 4). We did not test the effects of homelessness and transfer history because of the small number of cases that fell into those categories.

5. Discussion

We developed a prototype automated pressure ulcer risk assessment tool, BART and tested its performance with a small set of patient data. The “moderate” level of agreement with nurses in identifying the patients at risk for pressure ulcers indicates that further studies must be conducted to elucidate the origins of the differences. Furthermore, without a controlled study about patient outcomes it is difficult to know whether this decision support tool would improve care delivery. However, this study demonstrates potential for autopopulating the Braden Scale parameters based on detailed patient data and providing a preliminary score algorithmically.
To our knowledge, there have been no reports on this topic in the literature.

A third of the patient status descriptions extracted from the parameter definitions were either buried in free text or not documented at all. A couple of examples of undocumented items are “frequency of making position changes independently in the bed” and “frequency of changing bed linens.” It is unclear whether there is additional benefit to capturing these items other than for populating parameters on the Braden scale assessment. Although making data available and feasible for reuse is critical, this highlights the need to carefully decide what documentation items to include in structured format when designing a new electronic documentation system.

BART performed especially poorly on decisions about the Moisture Exposure parameter and the Nutritional Status parameter. BART determines the level of Moisture Exposure based on the frequencies of changing materials such as diapers/incontinence pads, bed linen, absorbent pads, or wound dressings. The score difference between the system and the nurses was minimal (i.e., 1 point) but this was the parameter least agreed on. BART tends to assign better scores than the nurses was minimal (i.e., 1 point) but this was the parameter least agreed on. BART tends to assign better scores than the nurses with this parameter. The nurses thought that the frequency of changing the listed materials reflected the pattern of moisture exposure implied by body temperature and presence of sweating and/or incontinence, but our results clearly show the opposite. In the future work, we are planning to evaluate different score definitions first (i.e., before introducing additional data items to the rule), such as adjusting cut off points and assigning different weights to each of the listed absorbent materials.

We found some limitations in the decision rule of the Nutritional Status parameter during the evaluation. NPO duration is one of the conditions incorporated into the rule. Following the parameter definitions provided by the Braden scale, we employed a cut off point of 5 days: greater than 5 days indicates “very poor” status, 1–4 days indicates “probably inadequate” status. The team realized that the status before NPO should be considered in this case because 1 day of NPO cannot be treated the same as 4 days of NPO, especially when a patient is just temporarily on NPO for a procedure. However, due to the lack of information on the nutritional intake pattern before hospitalization, this approach is not a viable option to assess those who are in the first or second day of NPO which started right on admission. The admission assessment documentation at the study hospital did not include prior food intake status. Therefore, we plan to incorporate laboratory values that can reflect a patient’s overall nutritional status in the future enhancement. Also, we will consider including a patient’s usual food intake pattern before admission as a nutritional assessment item in the new computerized documentation system.

Vague expressions in the parameter descriptions of the Braden scale made translating the described conditions into the decision rules challenging. Many key discriminators of the parameter scores are described in a non-quantifiable way, such as “makes major movement in bed” or “makes frequent position changes.” We have replaced these vague descriptions with more definite ones based on expert input. For example, the former was defined as “can roll side to side in bed.” In future studies, we will further assess nurses’ perceptions of these vague descriptions to more accurately quantify them. The use of better quantifiable descriptions will likely enhance consistency.

The ultimate goal of this project was to provide a means to auto-populate the Braden Scale with detailed patient data and then to allow the nurse to use clinical judgment to accept or to modify the scores as needed. The linkages between the identified risk and the supporting evidence i.e., detailed patient data were shown explicitly. BART currently provides risk scores, but we are completing a module in which a report is generated with the estimated risk scores and the detailed patient status information. This report will also present the additional risk factors such as immobility history, which are not a component of the Braden scale, so that nurses can incorporate the information into their decision-making process.

BART has been developed based on the data available at medical and surgical inpatient units at an academic medical center, and hence further validation in other settings is needed. In addition, after enhancing the decision algorithms as noted in the previous discussions, BART will need to be more rigorously evaluated for its performance with larger sample of patient data against carefully defined gold standards.

6. Conclusion

This study demonstrates the potential to algorithmically determine pressure ulcer risk based on detailed patient data. It is promising that the majority of the required data items are routinely documented. However, how to capture required data items that the current documentation system does not provide for reuse in BART remains an important challenge. If limitations are addressed, BART may contribute to improved efficiency and consistency of documentation, as well as quality of pressure ulcer care. It will do so by eliminating redundant documentation and data collection, and by providing evidence links between identified risks and supporting data.

Authors’ contributions

Hyoneui Kim designed the study, developed the decision rules, performed data collection, performed statistical data analysis, drafted and edited the manuscript. Jeeyae Choi designed the study, performed data collection for evaluation, performed analyses on the study outcome, and reviewed/edited the manuscript. Sarah Thompson developed the decision rules, performed data collection for evaluation and reviewed the manuscript. Lindsay Meeker developed the decision rules, performed data collection for evaluation and reviewed the manuscript. Patricia Dykes designed the study, reviewed and edited the manuscript. Denise Goldsmith designed the study, reviewed and edited the manuscript. Lucila Ohno-Machado reviewed and edited the manuscript, provided guidance on the overall manuscript and outcome analysis of the study.
Summary points
What was already known on the topic:

- Documenting patient data is one of many important nursing responsibilities but feasibility of using the documented data in a clinical nursing decision support system has not been well explored.
- Several studies reported developing a computerized pressure ulcer risk assessment tool based on expert rules. However, specific development methods and the performance evaluation of the tools have not been described in detail.

What this study added to our knowledge:

- Detailed experiences (including specific procedures) of developing an automated tool for pressure ulcer risk assessment.
- Promises and challenges of using documented data for automatically determining pressure ulcer risk scores.
- Informatics challenges in converting a paper-based assessment scale to a computerized tool.

Conflict of Interest

Authors do not have any conflicts of interest regarding this work. However, Denise Goldsmith is a member of the editorial board of IJMII.

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